Associative fear learning and perceptual discrimination: a perceptual pathway in the development of chronic pain

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Abstract

Recent neuropsychological theories emphasize the influence of maladaptive learning and memory processes on pain perception. However, the precise relationship between these processes as well as the underlying mechanisms remain poorly understood; especially the role of perceptual discrimination and its modulation by associative fear learning has received little attention so far. Experimental work with exteroceptive stimuli consistently points to effects of fear learning on perceptual discrimination acuity. In addition, clinical observations have revealed that in individuals with chronic pain perceptual discrimination is impaired, and that tactile discrimination training reduces pain. Based on these findings, we present a theoretical model of which the central tenet is that associative fear learning contributes to the development of chronic pain through impaired interoceptive and proprioceptive discrimination acuity.

Keywords

associative fear learning, perceptual discrimination, pain perception, chronic pain

1. Introduction

Pain has a high learning potency due to its intrinsically aversive nature and biological relevance for the organism's survival. A single occurrence of severe pain during a certain event can be sufficient to induce lifelasting fear of this event. Such fear is a potent motivator for anticipatory anxiety. An organism's ability to predict pain is crucial for survival, as it empowers individuals in their self-protective behavior, enabling avoidance of potential danger in the future. Associative learning processes have been studied using Pavlovian conditioning paradigms, in which an initially neutral stimulus (CS, conditioned stimulus) becomes associated with a motivationally relevant stimulus (US, unconditioned stimulus). As a result, the CS attains predictive value for the occurrence of the US and starts to elicit a conditioned response (CR) that is similar to the unconditioned response (UR) that was elicited by the US. Well known are Pavlov's dogs that started salivating in response to a tone that preceded the delivery of food (Pavlov, 1927). During differential learning, another "safe" stimulus (CS-) predicts the absence of the US. In the case of pain as a US, an increase in fear responses to the CS+ is generally observed as compared to the CS-. Although exteroceptive cues are predominantly used as CSs to model such learning processes (Aizenberg and Geffen, 2013; Resnik et al., 2011; Schechtman et al., 2010; Sehlmeyer et al., 2009), recent studies support the notion that fear learning can also occur to cues from within the body, such as interoceptive (De Peuter et al., 2011; Pappens et al., 2012; Van Diest et al., 2013) and proprioceptive sensations (Meulders et al., 2012, 2011; Trost et al., 2011). Interoceptive stimuli generate afferent signals from receptors that monitor the internal state of the body (e.g., gut sensations). Proprioceptive stimuli provide

information about posture and movement of the body (e.g., angular displacement sensations). Both are ecologically valid and likely better predictors of a pain US than exteroceptive cues, as they better reflect clinical reality in which individuals with chronic pain show a preoccupation with interoceptive sensations and certain movements as both often elicit anxiety (Labus et al., 2007; Sharma et al., 2010; Van Oudenhove and Aziz, 2013).

1.1. Perceptual alterations of the CS

Bodily sensations (CS) that through repeated associations with painful events become predictive of pain, could become aversive and attain US properties themselves. Generally, CSs become more aversive as a result of their associations with the US, a process called evaluative conditioning (De Houwer, 2007). More specifically, however, studies have demonstrated that following fear learning, exteroceptive CSs are perceived as not only more unpleasant, but also more intense (Asutay and Västfjäll, 2012; Stolarova et al., 2006). For instance, following aversive conditioning, loudness perception of the CS+ tone was increased (Asutay and Västfjäll, 2012). Importantly, this change can also include the transition from a non-painful to a painful sensation. In a study by Wiech et al. (2010) identical laser stimuli that had been calibrated to the pain detection threshold, were more often perceived as painful if the stimulus was preceded by a cue signaling that the stimulus would be applied to a site associated with threat. In analogy to these findings, normal, non-painful peristaltic sensations preceding painful abdominal cramps might become uncomfortable as a result of a conditioning process. Although a discussion of underlying processes remains speculative at this point, a

number of mechanisms are likely to contribute to this transition. First, increased arousal that accompanies fear learning might lead to an overestimation of stimulus properties of the CS (in this case the extent to which the CS is perceived as painful). For example, Stefanucci and Strobeck (2009) demonstrated the influence of arousal on height perception with height being overestimated during periods of elevated arousal (Stefanucci and Storbeck, 2009; Teachman et al., 2008). Further evidence for an influence of arousal comes from a study in patients with irritable bowel syndrome who rated identical visceral stimuli as more unpleasant and intense when in a state of heightened arousal compared to a relaxation condition (Dickhaus et al., 2003). Second, the emotional significance of bodily sensations associated with pain might lead to an amplification of cortical responses (Pourtois et al., 2013; Vuilleumier, 2005). Various studies have reported enhanced neural responses to emotional stimuli both in cortical and subcortical brain regions, including sensory processing areas and limbic regions (Armony and Dolan, 2002; Ethofer et al., 2012; Luo et al., 2010; Padmala and Pessoa, 2008; Sabatinelli et al., 2011). According to the Multiple Attention Gain Control (MAGiC) model (Pourtois et al., 2013), emotionally-laden stimuli are capable of engaging fast-acting emotional neuronal systems which can alter attentional and perceptual systems and thereby influence perceptual processing of those emotional stimuli as well as other stimuli. Third, bodily sensations associated with pain might be capable of triggering aversive memory networks due to their emotional valence and close link to pain. The engagement of such networks has been implicated in perceptual changes in the context of pain (Apkarian et al., 2011, 2009). The activation of pain-related memories would thereby bias the perceptual process

towards pain and favor the interpretation and experience of previously non-painful stimuli as painful. Although these different mechanisms were discussed separately here, they are not mutually exclusive but likely to complement each other.

1.2. Fear learning, defensive behavior and chronic pain

Research on interoceptive and proprioceptive fear learning has mainly emphasized behavioral outcomes, such as respiratory behavior in the context of fear of suffocation (Pappens et al., 2013), escape and avoidance behavior in musculoskeletal pain (Vlaeyen and Linton, 2000, 2012), gastrointestinal-specific anxiety in visceral pain (Labus et al., 2007, 2004; Van Oudenhove and Aziz, 2013) and conditioned nausea in cancer patients (Stockhorst et al., 2007). Meulders and colleagues have recently developed an experimental paradigm of fear learning with proprioceptive CSs using the Voluntary Joystick Movement task (Meulders et al., 2013, 2012, 2011). Furthermore, interoceptive paradigms have used aversive visceral balloon distensions as US (Benson et al., 2014; Kattoor et al., 2013; Yágüez et al., 2005) or rotations as nausea-inducing stimuli (US) (Klosterhalfen et al., 2000; Stockhorst et al., 2006). Research on conditioned nausea has demonstrated that (non-painful) bodily sensations or symptoms can arise as a result of associative learning. Studies using visceral balloon distensions have focused on conditioned fear responses to exteroceptive stimuli (CSs) predicting visceral pain and neural networks involved in the acquisition and maintenance of fear of visceral pain. Although the visceral US varied in these interoceptive fear conditioning paradigms (e.g., rectal or esophageal balloon distension) they all used

visual cues as CS. Only few studies have used interoceptive CSs (Pappens et al., 2013, 2012; Van Diest et al., 2013).

Importantly, the Fear-Avoidance model has instigated treatments targeting dysfunctional avoidance behavior (i.e., graded exposure to feared movements to inhibit conditioned fear responses) (Boersma et al., 2004; de Jong et al., 2005; Leeuw et al., 2007; Vlaeyen et al., 2002). In a similar vein, the concept of gastrointestinal specific anxiety has inspired the development of exposure therapy for functional gastrointestinal disorders (Craske et al., 2011; Ljótsson et al., 2014; Van Oudenhove and Aziz, 2013). Visceral symptoms improved following reduction of gastrointestinal specific anxiety by repeated exposure to visceral sensations (Craske et al., 2011; Ljótsson et al., 2014). Ljótsson and colleagues developed an internet-delivered cognitive behavioral therapy protocol that included an exposure procedure in which subjects are gradually exposed to irritable bowel syndrome (IBS) symptoms by engaging in various activities such as eating symptom provoking foods or physical activities (Ljótsson et al., 2014, 2013, 2011). The rationale of these interventions is that persistence of avoidance behavior results in the maintenance of fear responses, and interference with daily activities. In addition, there is emerging evidence showing fear learning or extinction deficits in chronic pain patients. Fibromyalgia patients displayed reduced contingency awareness and safety learning compared to healthy controls in a differential fear conditioning paradigm (Jenewein et al., 2013; Meulders et al., in press). Schneider and colleagues (2004) showed elevated conditioned responses during extinction in chronic back pain patients compared to controls in addition to acquisition differences. Following pairing of a visual cue with a painful stimulus applied to the

abdomen, IBS patients had higher skin conductance responses during extinction compared to controls (Labus et al., 2013). Further support for altered fear learning and extinction comes from studies on anxiety disorders which often co-occur with chronic pain (Bouton et al., 2001; Lissek et al., 2005; Mineka and Oehlberg, 2008).

1.3. Fear learning, perception and chronic pain

While acknowledging that behavior is an important and treatable component of chronic pain, less scientific attention has been paid to how associative fear learning affects the perception of bodily sensations in general and pain perception in particular. Here, we argue that the effects of associative fear learning on the perception of bodily sensations, which may be mediated through perceptual discrimination (i.e., reduced discrimination acuity of bodily sensations), are especially relevant for contemporary chronic pain models. Fear learning during acute pain is thought to impair one's ability to discriminate between bodily sensations (CSs) associated with pain (see Fig. 1). As a consequence of these learning processes, pain-related expectations arise in response to the CS (Vlaeyen and Linton, 2000, 2012), which bias perceptual decision-making towards pain (Wiech et al., 2014). The combination of these processes may result in a lower perceptual accuracy of pain-related sensations (Wiech et al., 2014). Note that perceptual accuracy and discrimination are closely related but not identical, as the former is considered to be an outcome, while the latter is a process that changes over the course of the chronification process. Over time, the perception of interoceptive and proprioceptive stimuli associated with pain changes. The driving mechanism behind these changes remains unclear but contemporary theories

assign a critical role to anxiety and fear (Vlaeyen et al., 2012; Vlaeyen and Linton, 2012), as they are thought to bias perception towards pain (Apkarian et al., 2011, 2009). Thus, due to their association with pain these bodily sensations become aversive (De Houwer, 2007; De Peuter et al., 2011; Van Oudenhove and Aziz, 2013; Vlaeyen and Linton, 2000) and with time elicit sensations of pain. As a consequence of this shift, discrimination impairments that previously applied to these interoceptive and proprioceptive stimuli, result in an impaired discrimination of painful and non-painful sensations (see Fig 1). Within this framework, the role of attentional process should be further explored, especially the concept of hypervigilance given its association with pain (Van Damme et al., 2006; Vlaeyen and Linton, 2000). Hypervigilance originates as a consequence of a heightened perception of threat and might bias pain perception, as the body is scanned for threats (Crombez et al., 2005). This detection of potentially threatening stimuli could be at the expense of a more thorough processing of sensory input and might result in the misclassification of bodily sensations as painful.

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2. Perceptual discrimination and chronic pain

Interoceptive stimuli are often complex constellations of features on multiple dimensions (e.g., modality, intensity, location, unpleasantness). Their representation consists of a graded pattern of activation across a range of units for multiple dimensions simultaneously (McLaren and Mackintosh, 2000). Perceptual discrimination is the ability to distinguish stimuli that differ in at least one

dimension. In the context of chronic pain it can apply to the ability to distinguish between different non-painful bodily sensations (CSs vs. similar stimuli, e.g., more or less intense stimuli), between different sensory qualities of pain (burning vs. pricking), or between painful and non-painful bodily sensations.

Despite a few exceptions (Peters and Schmidt, 1992, 1991), the majority of the clinical studies point to an impaired perceptual discrimination in individuals suffering from chronic pain. Most studies have investigated discrimination between non-painful bodily sensations only, and a few have focused on discrimination between painful and non-painful stimuli. A reduced tactile acuity (i.e., keenness of the sense of touch) in body regions affected by chronic pain has been observed in individuals with complex regional pain syndrome (CRPS) (Maihöfner and DeCol, 2007; Maihöfner et al., 2006; Moseley et al., 2008; Pleger et al., 2006, 2005; Wand et al., 2010), upper limb peripheral nerve transection, surgical repair (Taylor et al., 2010), and chronic back pain (Moseley, 2008). Other studies have reported a reduced proprioceptive discrimination (Flor et al., 1999, 1992) and impaired radiant heat pain discrimination (Cohen et al., 1983) in chronic back pain patients. In the same vein, irritable bowel syndrome patients show difficulties with discriminating between noxious and non-noxious rectal balloon distentions (Dorn et al., 2007; Naliboff et al., 1997; Wilder-Smith and Hill, 2003). Various mechanisms have been postulated for reduced discrimination abilities in chronic pain patients, including peripheral mechanisms (Maihöfner and DeCol, 2007), changes in the central nervous system both at the spinal level (e.g., presynaptic inhibitory mechanisms) (Bardoni et al., 2004; Jänig and Zimmermann,

1971) and the brain (e.g., reorganization at the level of the somatosensory cortex) (Pleger et al., 2005, 2003).

In addition, training of perceptual discrimination in different pain disorders generally reduced pain reports, although more studies are needed before drawing firm conclusions. Tactile discrimination training decreased phantom limb pain (Flor et al., 2002; Weiss et al., 2010), and pain in CRPS patients (Moseley and Wiech, 2009; Moseley et al., 2008). Also in other treatments, improvements in sensory discrimination often occur in parallel with pain reduction. For example, a study using repetitive transcranial magnetic stimulation over the motor cortex in chronic neuropathic pain patients induced pain relief, which was associated with improved sensory discrimination at the affected location (Wassim et al., 2013). Graded sensorimotor retuning therapy in CRPS patients produced pain reduction paralleled by an improved tactile discrimination (Pleger et al., 2005). Recently, improved perceptual discrimination has been suggested to mediate the observed analgesic effects of acupuncture (Wand et al., 2013). Reduced use of body parts has been found to impair perceptual discrimination (Lissek et al., 2009). In a similar vein, one of the mediating factors of exposure therapy, which is designed to reduce pain-related fear (Vlaeyen et al., 2012), could be unintended discrimination training. Indeed, reengagement in previously avoided activities simultaneously increases the exposure to interoceptive and proprioceptive sensations in the affected body parts.

3. Fear learning and perceptual discrimination

Only a limited number of studies have investigated the effects of associative fear learning on perceptual discrimination (operationalized as the ability to discriminate between the CS and similar stimuli), and even less studies have used interoceptive and proprioceptive stimuli, which are relevant for chronic pain. Li and colleagues (Li et al., 2008) demonstrated the effect of aversive conditioning on odor discrimination. Odor enantiomers (mirror-image molecules with an identical initial smell) were used as CSs. Discrimination improved following fear learning for the CS+ enantiomers, but not for the control CS- enantiomers. Interestingly, this was paralleled by differential activation patterns in the piriform cortex: whereas the fear learning procedure produced more divergent spatial activity patterns for the CS+ pair, patterns for the CS- pair remained stable and highly correlated. These findings were replicated in a recent behavioral study (Åhs et al., 2013), and are in line with observations from an electroencephalography study using a differential fear conditioning paradigm (Diesch and Flor, 2007). The latter study applied two innocuous electric stimuli to the left and right index as CS+ and CS-, and a noxious electric stimulus to the lower back as US. In one group the CS+ predicted the US, while in the other the US was truly randomly presented. Dipole orientations for CS+ and CS- diverged in the paired group after acquisition, while they remained the same in the random group. Resnik and colleagues (Resnik et al., 2011) used tones (1 and 2 kHz) as CS+ and CS-, and an aversive odor as US. Following fear learning, participants perceived tones near the frequency of the CS+ more often as identical to the CS+. Also Schechtman and colleagues used two tones as CS+ and CS- (300 and 700 Hz), but applied monetary loss and gain as US for the CS+ and CS- respectively (Schechtman et al., 2010). Again, aversive learning led to poorer

perceptual discrimination indexed by a broader array of tones identified as CS+. A similar but less profound decrease in discrimination performance was observed for stimuli around the CS- compared to stimuli around a neutral tone. A recent animal study revealed that the effect of auditory fear conditioning on tone discrimination can occur in either direction, and does not necessarily imply a *reduction* in perceptual discrimination (Aizenberg and Geffen, 2013). Differential conditioning with closely resembling CS+ and CS- increases discrimination while differential conditioning with physically distant CS+ and CS- decreases discrimination acuity of tones around the CS+ tone (Aizenberg and Geffen, 2013). In a same vein, simple aversive conditioning (CS+, no CS- presented) led to generalized fear while differential learning (CS+ and CS-) led to more stimulus-specific freezing in rats (Chen et al., 2011), suggesting increased perceptual acuity in the latter compared to the former paradigm.

Collectively, these studies –albeit scarce- consistently support the idea that associative learning influences perceptual discrimination. Indeed, the abovementioned studies suggest an inverse relationship between the physical CS+/CS distance and subsequent changes in perceptual discrimination. The study by Aizenberg (2013) illustrates that although fear learning leads to reductions in perceptual discrimination, the particular features of the CS- presented during differential fear learning seem to moderate this effect. Large differences between CS+ and CS- appear to result in a reduction in perceptual discrimination. In contrast, small CS+/CS- differences (e.g., indistinguishable odor entiomers as in Li et al. 2008) seem to improve rather than deteriorate perceptual discrimination after fear learning. Further work is required in order to identify the point along

this distance continuum at which the direction of the relationship with perceptual discrimination changes for different sensory modalities. Based on these observations we suggest that these different learning experiences during acute pain could explain different trajectories in the development of chronic pain. Generally, the experience of acute pain triggers automatic fear learning processes. These will, however, not result in the same learning experience for every individual. For example, simple fear learning is more likely to occur when individuals engage in excessive avoidance behavior. The association of pain with a movement and subsequent avoidance of all related movements prevents an active exploration of which movements or sensations lead to pain and which ones do not (i.e., differential fear learning with small CS+/CS- physical differences). As a consequence the accuracy of interoception and proprioception degrades, thereby fostering the transition from acute to chronic pain. However, it remains unclear which contextual and cognitive-emotional factors further shape either of these individual learning experiences.

4. Chronic Pain Theories

Ample evidence supports the notion that pain perception is not a stable construct, but a noisy inferential process prone to errors (Apkarian et al., 2011, 2009; De Ridder et al., 2011). The perceptual process does not occur in isolation but interacts with expectations, memory networks, emotional states, and learning processes. Based on functional magnetic resonance imaging studies in patients with different chronic pain syndromes, it has been suggested that a biased aversive memory network originates from automatic associative learning

processes (Apkarian et al., 2011, 2009; De Ridder et al., 2011), thereby influencing perception and its underlying sensory-discriminative processes. The idea is that pain induces long-term memories through conditioning mechanisms, resulting in the reorganization of limbic structures, including medial prefrontal areas and subcortical structures such as the dorsal and ventral basal ganglia, amygdala and hippocampus. This learning-induced plasticity in turn influences sensory and cognitive processing areas and alters the modulation of interoceptive and proprioceptive afferent input. However, the precise relation between perception and associative learning as well as the underlying mechanisms remain to be unraveled. Using a computational model (i.e., the Hierarchical Drift Diffusion model (Vandekerckhove et al., 2011), we recently demonstrated that the expectation of high pain biased perceptual decision-making towards the expected sensation (Wiech et al., 2014). In this framework, fear learning is hypothesized to bias this perceptual process by reducing the amount of evidence that is needed to classify the perception as the feared outcome, without changing sensory processing (Ratcliff and McKoon, 2008; Wiech et al., 2014). On a more cognitive-behavioral level, Vlaeyen and Linton (Vlaeyen and Linton, 2000, 2012) attribute a central role to associative learning mechanisms in the pathogenesis of chronic musculoskeletal pain, with avoidance behavior to conditioned stimuli as the key mediator to pain persistence and disability.

Here, we further build upon these contemporary theories by suggesting that (I) associative fear learning influences the perception of the CS. The more threatening the US is perceived (i.e., due to catastrophic misinterpretations of pain, avoidance behavior, etc.), the more likely that CSs become aversive

themselves, and obtain US properties. (II) Fear learning influences the ability to discriminate between different bodily sensations. The larger the CS-/CS+ distance during acquisition, the worse the perceptual discrimination between the CS and similar stimuli. Avoidance of stimuli similar to the CS prevents the individual from learning that these stimuli predict the absence of the US (thus act as CS-). (III) Moreover, and by virtue of the learned CS-US association, the 'incorrect' CS percepts will foster the expectation of the US. (IV) US expectancies bias the perceptual process towards pain, increasing the likelihood of the perception of pain, thereby reinforcing previously established CS-US associations. (V) As CSs shift on valence and attain US properties, previously established discrimination impairments now also include the difficulty to discriminate between non-painful and painful bodily sensations. As a result, the frequency, magnitude and extent of pain episodes increases, and acute pain gradually develops into a persistent pain state. Given that bodily sensations consist of a constellation of features in different dimensions, discrimination impairments could occur along any of these dimensions. In addition, these changes in discrimination might generalize across dimensions or locations, further fueling the development of chronic pain. Thus, impaired discrimination acuity in combination with a biased perceptual process originating from expectations and memories enhance the development of chronic pain. In Figure 2 a schematic overview of this process is provided.

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5. Neural mechanisms

Over the recent years, extensive research has identified brain regions and neural mechanisms involved in perceptual learning, discrimination and decision-making in the somatosensory system (for an overview see Romo et al., 2012). However, so far only little is known about the neural mechanisms underlying the influence of fear learning on perceptual discrimination. There is first evidence from animal studies showing that the auditory cortex is involved in fear-induced changes in sensory acuity. Temporary inactivation of the auditory cortex after fear learning abolished learning-induced effects on auditory discrimination accuracy (Aizenberg and Geffen, 2013). However, this manipulation alone did not affect discrimination accuracy in a control group nor did it influence the specificity of the change (i.e., whether fear learning leads to a decrease or increase in discrimination acuity). Instead, Laufer and Paz (2012) demonstrated the involvement of the amygdala in changes in perceptual discrimination related to fear-learning. After an aversive learning procedure, they found higher amygdala activity during trials in which a tone similar to the CS tone was misidentified as the CS. Given that the amygdala has strong bidirectional connections with primary sensory cortices (Amaral et al., 2003; Catani et al., 2003), it has been postulated that input from this region can alter processing in sensory cortices and thereby bias perception. In line with this notion, there is accumulating evidence from the visual domain showing that the amygdala is critical for gain control observed in the visual cortex (for review see Pourtois et al., 2013). Gain control is commonly reflected in an increased amplitude of neural responses to threatening stimuli and/or earlier neural responses. Lesions of the amygdala have been shown to abolish the enhancing effect (Rotshtein et al., 2010; Vuilleumier et al., 2004). Besides an influence

through direct connections, the modulatory effect of the amygdala might also be implemented through indirect pathways via brain regions such as the orbitofrontal cortex (see Pourtois et al., 2013). So far, most insights into the influence of fear and anxiety on sensory processing have come from research in the visual and auditory domain. How these findings translate to the somatosensory system and pain is still unclear.

6. Conclusion

We presented evidence for a close relation between associative fear learning processes and perceptual discrimination, which in turn can influence pain perception. Reported opposite effects suggest a critical role of learning experience, although the role of other variables remains to be elucidated. More research is needed to understand which contextual and cognitive-emotional factors shape learning experiences. Based on the research reviewed here we suggest that the effect of associative fear learning on perceived pain intensity is mediated by perceptual discrimination, and that the relationship between these processes constitutes the driving mechanism in the transition from acute to chronic pain states. This model, however, needs to be further tested and validated using clinically relevant paradigms. Future research is needed to investigate the transdiagnostic nature of these mechanisms and potential differences between chronic pain types or diagnoses.

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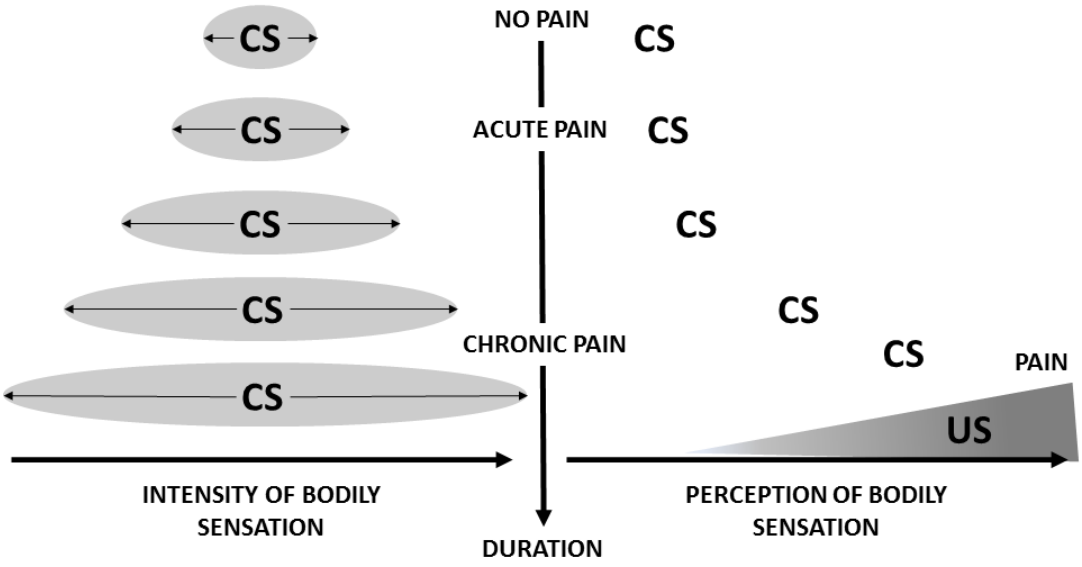
Appendix. Figure 1.

Caption Evolution of discrimination acuity and perception of bodily sensations during chronic pain.

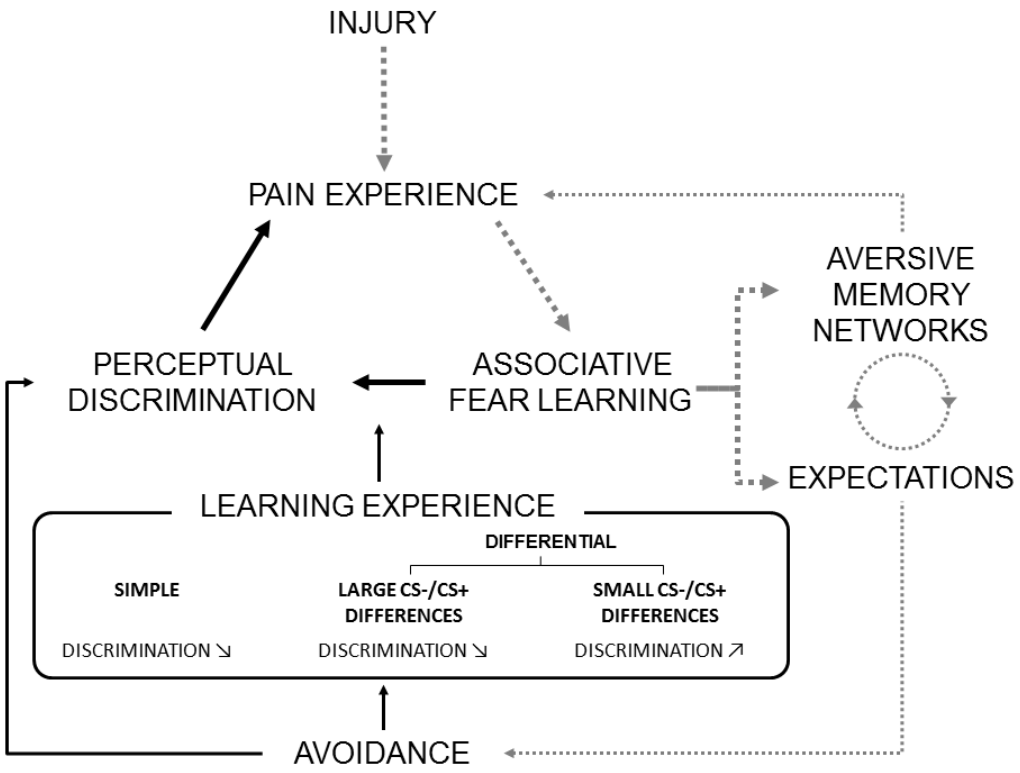


Description: Figure 1. Graphical illustration of the evolution of discrimination acuity and perception of bodily sensations in chronic pain. During acute pain fear learning can result in reduced perceptual discrimination, i.e., a reduced ability to discriminate between the CS and similar stimuli (more or less intense stimuli), in this example on the intensity dimension (left panel). The relationship between discrimination acuity and physical distance between the CS and similar stimuli is represented by the grey ellipses. The ellipses represent compromised acuity in discriminating between the CS and similar stimuli despite increased physical dissimilarity between stimuli. In addition to decrements in discrimination acuity with disease progression, the perception of the CSs might also change. CSs can acquire US properties (right panel) and therefore shift on the axis in a non-linear

fashion (exponential decay). As a consequence of this shift, discrimination impairments that previously applied to these interoceptive and proprioceptive stimuli, result in an impaired discrimination of painful and non-painful sensations. CS = conditioned stimulus, US = unconditioned stimulus

Figure 2.

Caption Theoretical model of fear learning effects on pain perception



Description: Figure 2. Graphical display of the relationships between associative fear learning, perceptual discrimination, and the experience of pain. The grey dotted arrows represent previously established relationships. The black arrows represent the proposed pathways of the theoretical model. Fear learning results in a biased pain perception via aversive memory networks and expectations. In addition, fear learning to interoceptive and proprioceptive sensations affects perceptual discrimination of bodily sensations. A degraded discrimination results in more intense and frequent pain experiences. The type of learning experience moderates the fear learning – perceptual discrimination relationship. Avoidance

behaviour influences the learning experience but also has a direct effect on perceptual discrimination.

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